Numerical Simulation of Event 191-6 of NASA's Flight Tests

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Outline

- Introduction
- Description of Turbulence Event
- TASS Model
- Initial Conditions
- Results from Model Simulation
- Summary

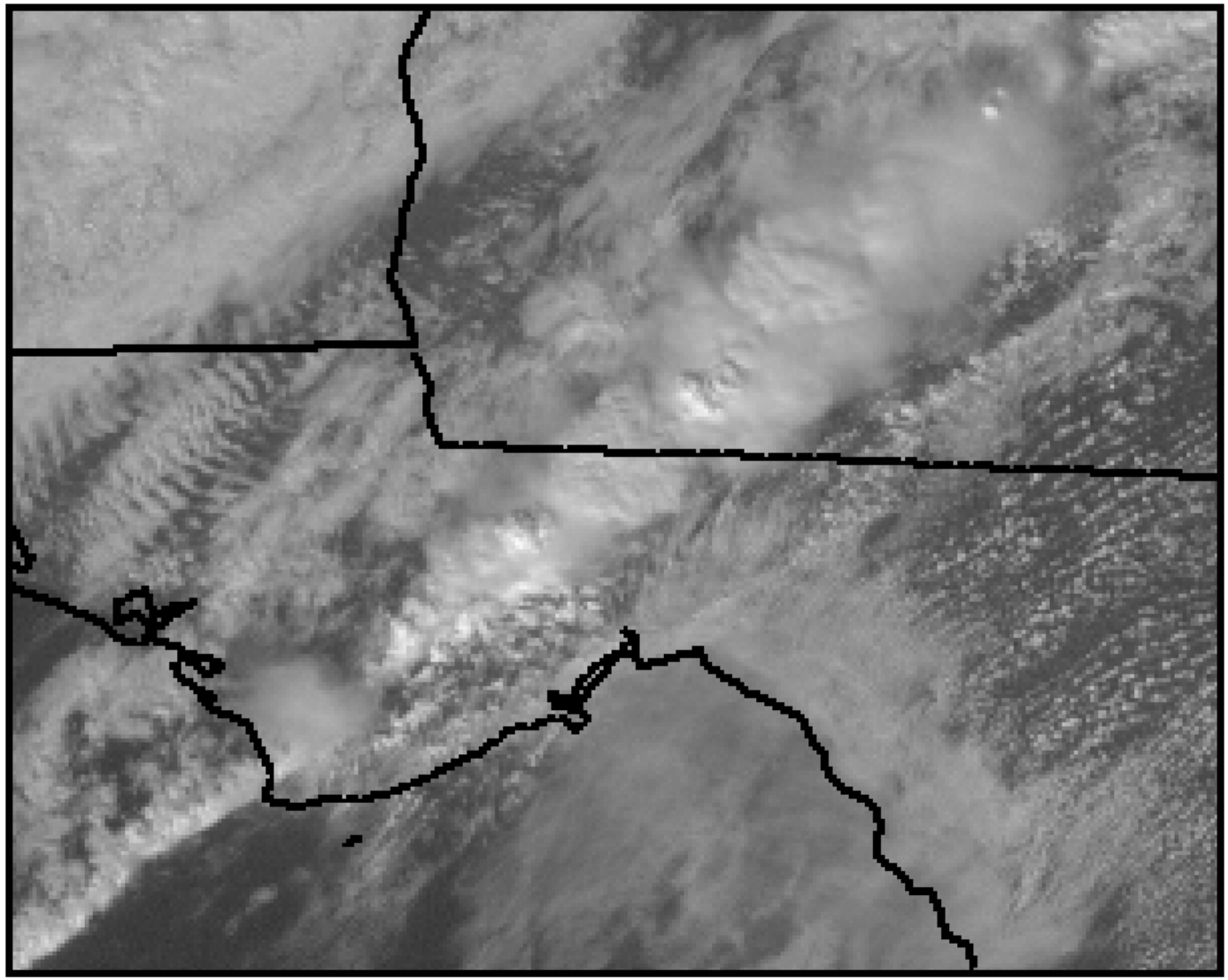
Introduction

- Numerical Simulation of Event 191-6
- Severe Turbulence Encountered by NASA Langley B-757 during Event 191-6
- Occurred as B-757 Penetrated Updraft Plumes Near Storm Top
- Data Available for Model Validation
  - Ground Based Radar (i.e. Nexrad)
  - Satellite
  - NASA B-757
    - *In Situ* Winds and Accelerations
    - Onboard Doppler Radar
    - Eyewitness Accounts

R – 191-6 December 14, 2000

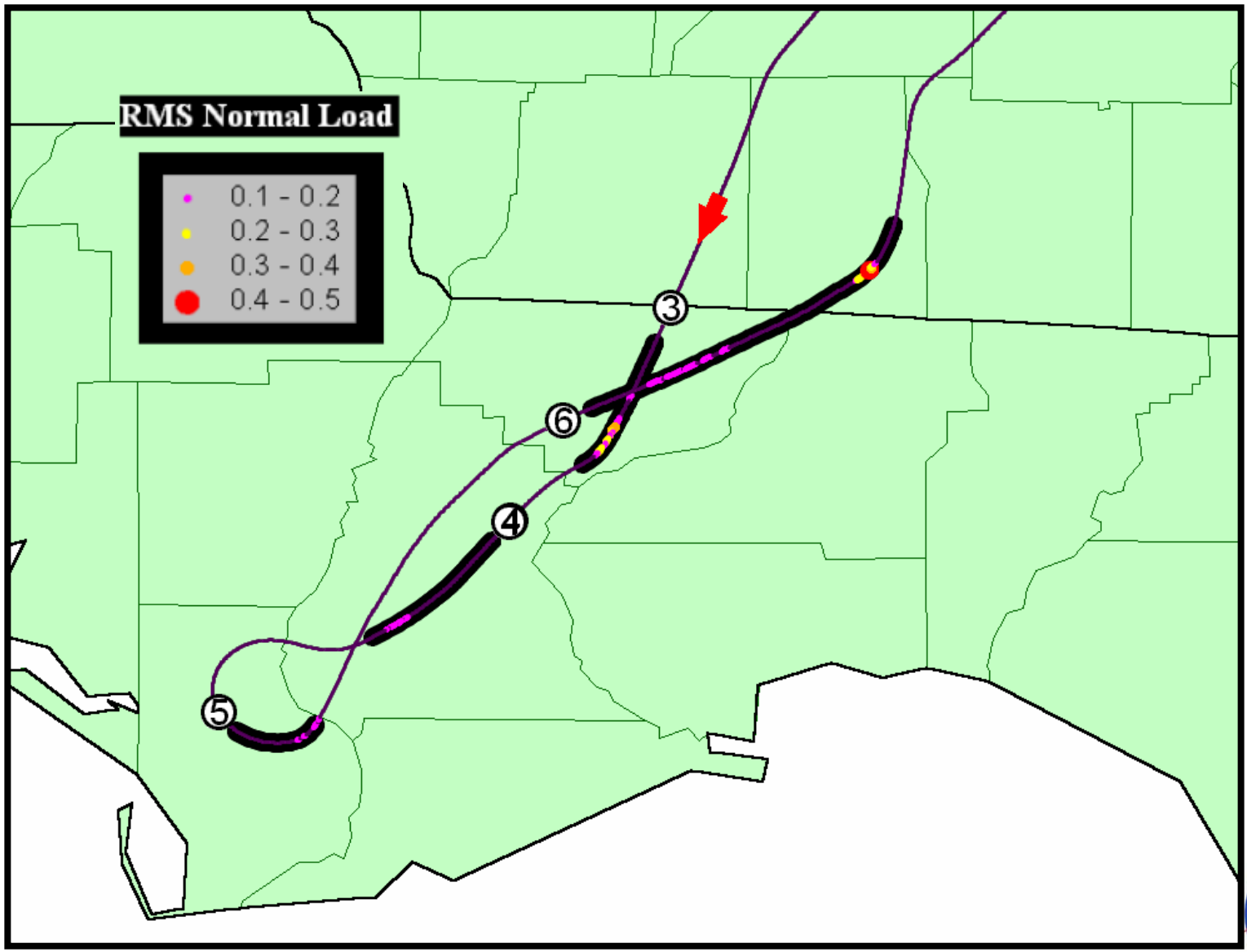
- **Severe turbulence encountered Approximately 40 *km* ENE of Tallahassee FL**
- **Narrow line of convective cells**
  - **Peak storm tops: 39,000 *ft* *(11.8 km)***
  - **Cell movement: from southwest at 40 *kts***
- **2 significant turbulence events with peak *in situ* measurement:**
  - $\sigma_{\Delta n} = 0.44$
  - $\varepsilon^{1/3} = 0.84$

1 km Visible Satellite
1845 Z December 14, 2000



FHP-DWH

Flight Path – RMS Normal Loads



MODELING ROADMAP

- **Step 1: Derive initial sounding based on mesoscale model prediction; configure domain; retrieve and prepare observed data for case verification.**
- **Step 2: Coarse-grid simulation: should capture large scale characteristics of storm: 125x125x70 grid points with horizontal grid size of 200 *m***
- **Step 3: Fine-grid simulation: 250x250x150 grid points, with grid size of 100 *m***
- **Step 4: Nested grid simulation**
  - **5 km region near cloud top**
  - **Minimum grid size less than 25 m.**
  - **Validate results**

TERMINAL AREA SIMULATION SYSTEM (TASS)

- 3-D Large Eddy Simulation (LES) Model
- Meteorological Framework
- Prognostic Equations for:
  - 3-Components of Velocity - Pressure
  - Potential Temperature - Rain
  - Water Vapor - Snow
  - Liquid Cloud Droplets - Hail/graupel
  - Cloud Ice Crystals - Dust/insects/tracers

- 1st-order subgrid turbulence closure with Richardson-number dependency
- Surface friction layer based on Monin-Obukhov similarity theory
- Cloud microphysics

TASS -- History

- Development began in 1983 for NASA/FAA Windshear Program
- Recently applied in NASA's Wake Vortex Program for improving airport capacity (i.e. AVOSS)
- Generation of data sets for Windshear Sensor Certification
- Supported NTSB Investigation of 1994 Charlotte and 1999 Little Rock Aircraft Accidents
- Simulations Applied to:
  - Cumulonimbus Convection
  - Tornadic Storms & Supercell Hailstorms
  - Microbursts & Microburst Producing Storms
  - Reconstruction of Microburst Windshear Encounters
  - Aircraft Wake Vortices
  - Atmospheric Boundary Layer
  - Flight Turbulence

R-191-6, 14 Dec 2000, Near Tallahassee FL

TASS Domain Configuration

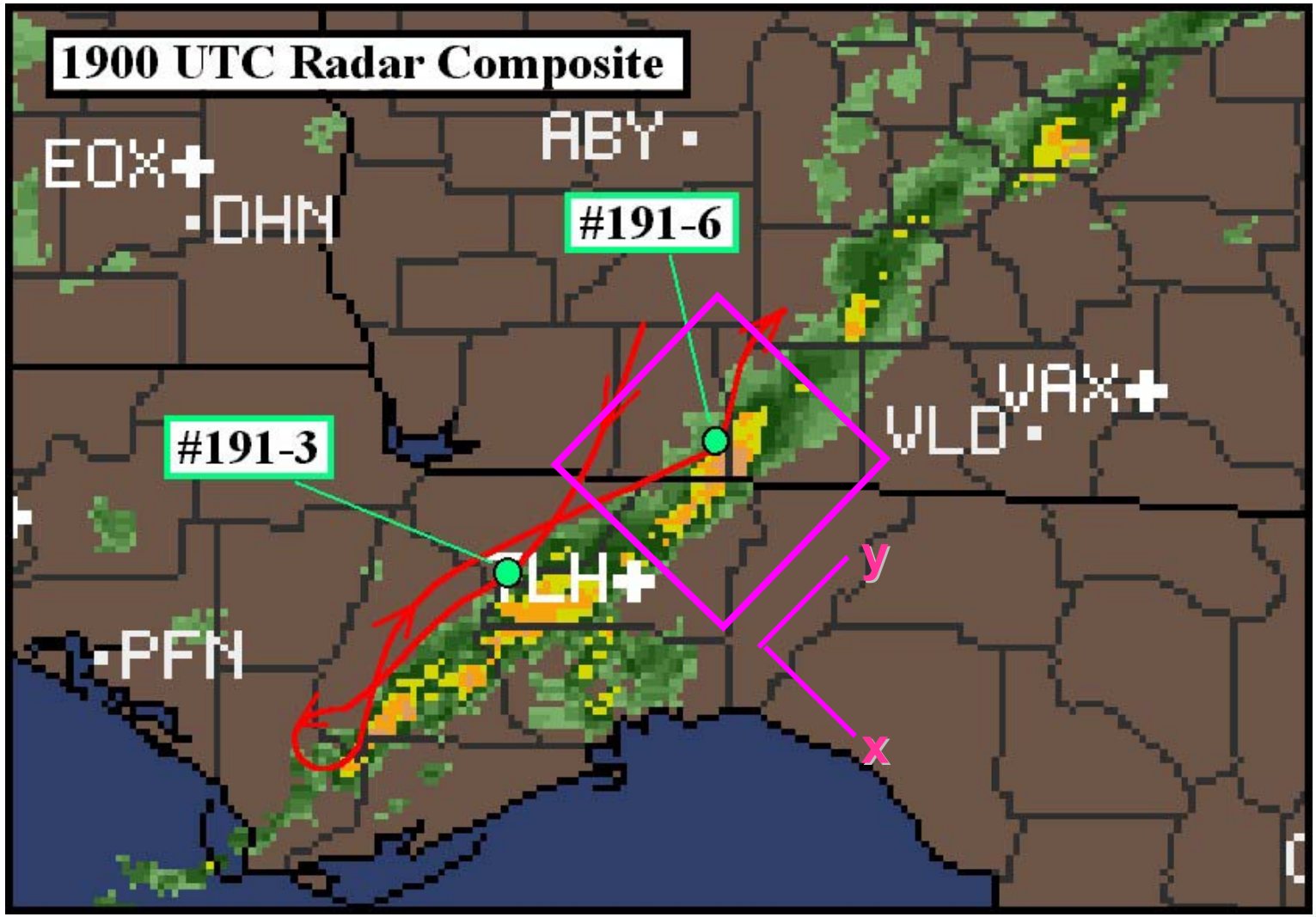
Physical Domain size

- Horizontal (*X,Y*): 25 x 25 km
- Vertical (*Z*): 14 km

Domain orientation and lateral boundary conditions

- Domain rotated 66^{o} clockwise:
  - *X* – coordinate orthogonal to convective line
  - *Y* – coordinate along line
- Lateral BC:
  - Periodic boundary at *Y*= {0, *X**},
  - Open at *X*= {0,*Y**}
- Computational resolution
  - Horizontal – 100 *m* (251 x 251 grid points); can resolve horizontal scales down to *400-200 m*
  - Vertical – 100 *m* , stretched grid at *Z*<2100 *m* with grid size decreasing to 50 *m* at *Z*=0 (148 levels)

Flight 191 – Path with Nowrad



TASS Simulation of Event 191-6, 14 Dec 2000

TASS Input Data

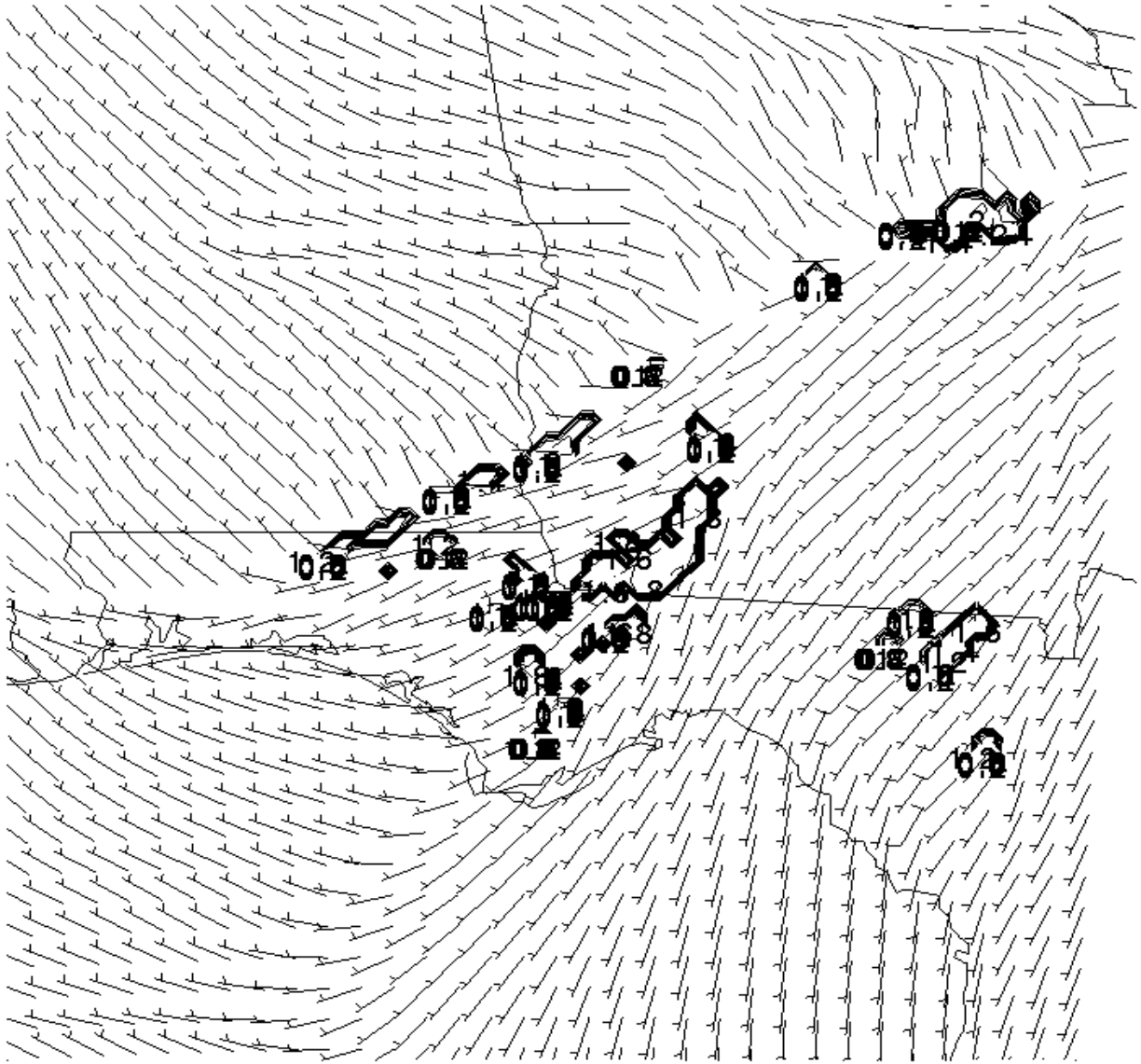
Input Sounding

- Environmental winds, temperature, dewpoint, & pressure
- From MASS 6-km forecast at time & location near event
- Boundary layer temperature & moisture from TLH observation

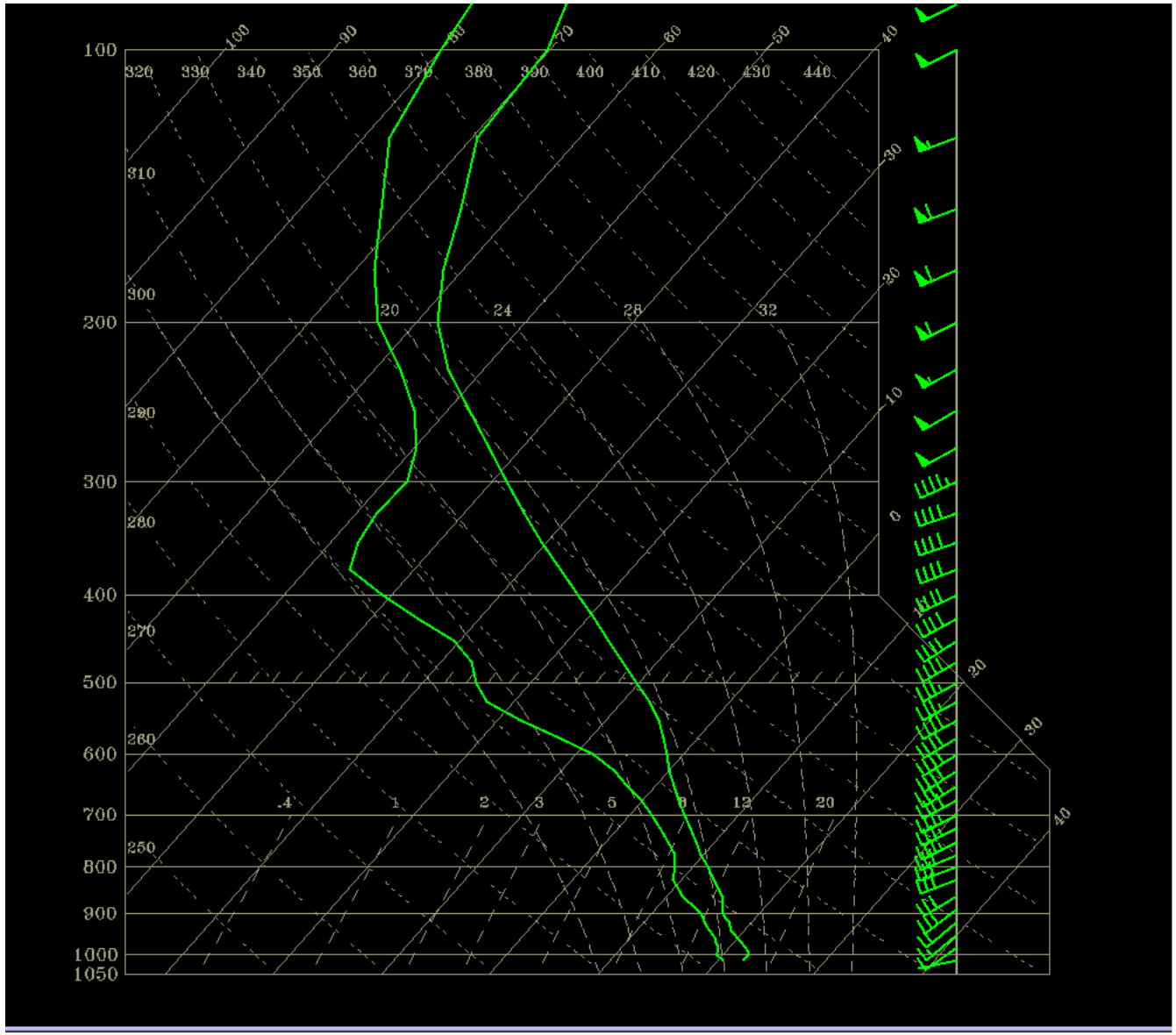
Convection initiated at model time zero

- Spheroidal thermal impulse
  - Peak amplitude 2.0^{o} C
  - Dimensions – 4 km horizontal x 2.1 km vertical

MASS Surface Precipitation



MASS TLH sounding



FHP-DWH

TASS Simulation of Event 191-6, 14 Dec 2000

Simulated Storm Characteristics

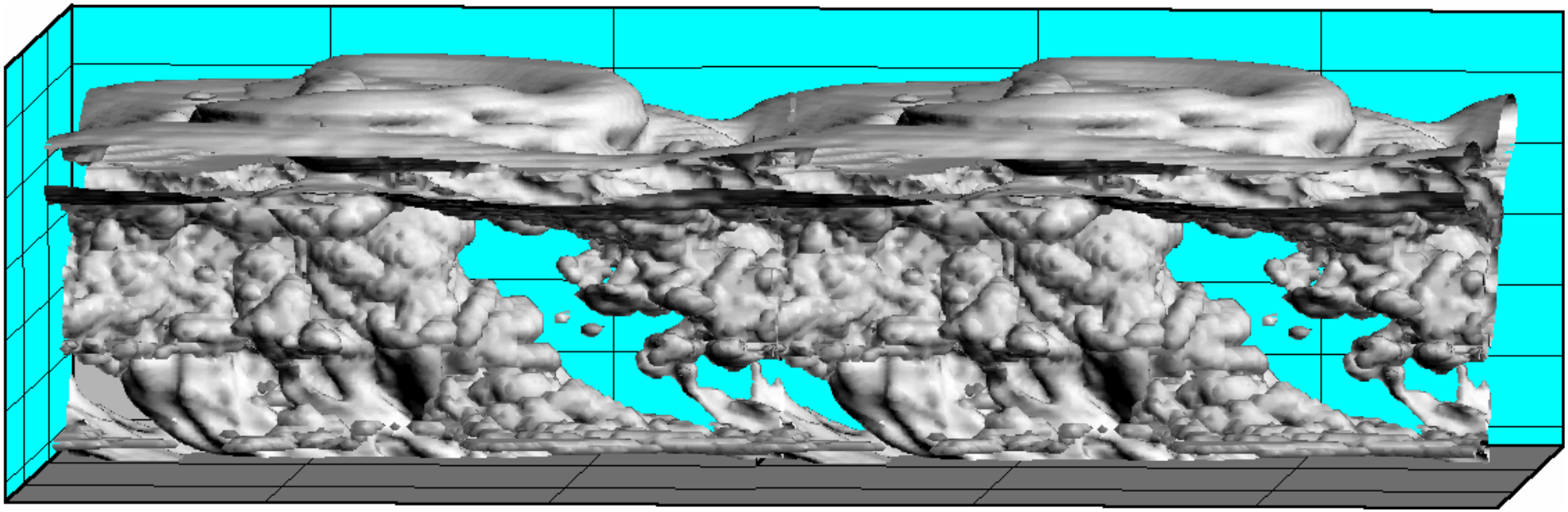
- Near solid line of convection
- Overshooting tops to 11.5 *km (38,000 ft)*
- Cell motion: 19 *m/s* (37 *kts*)
- Moderate rainfall at surface (no hail)
- Persistent multi-cell type convection
- Turbulence associated with storm tops
- Cloud top rise rates about 10 – 12 *m/s (30-40 ft/s)*

Variable	TASS		Observed	
Peak Storm Tops	11.5 *km*		11.8 *km*	
Peak Radar Reflectivity at Ground	53.5 *dBz*		55 *dBz*	
Peak Radar Reflectivity at *z*=9 *km*	38.9 *dBz*		40 *dBz*	
Cell Motion (toward)	ENE at 19 *m/s*		ENE at 17 *m/s*	
Width of Convective Line near Ground Level (based on 20 *dBz*)	6 *km*		8 *km*	
Peak Vertical Velocity at Flight Level (*z*~10.3 *km*)	Max 17 *m/s*	Min -11 *m/s*	Max 17 *m/s**	Min -12 *m/s**
Peak Eddy Dissipation Rate ($m^{2/3}/s$)	0.86		0.8	
Horizontal Scale of Turbulence Patch at Flight Level	5 *km*		5 *km*	

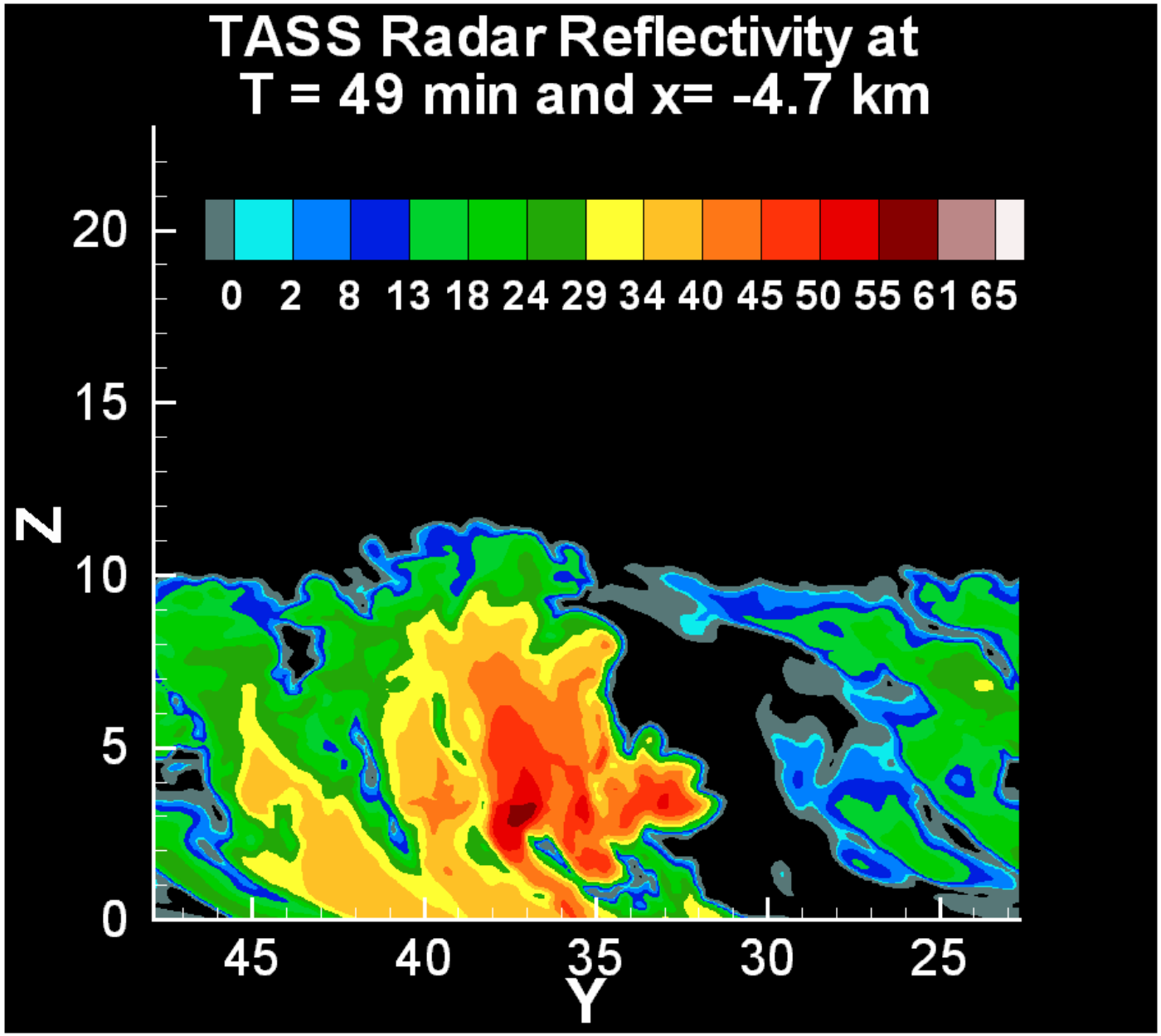
On Approach to Convection

TASS Simulation

viewed from northwest
(cloud/precipitation surfaces)



TASS Vertical Cross Section of RRF (dBz)



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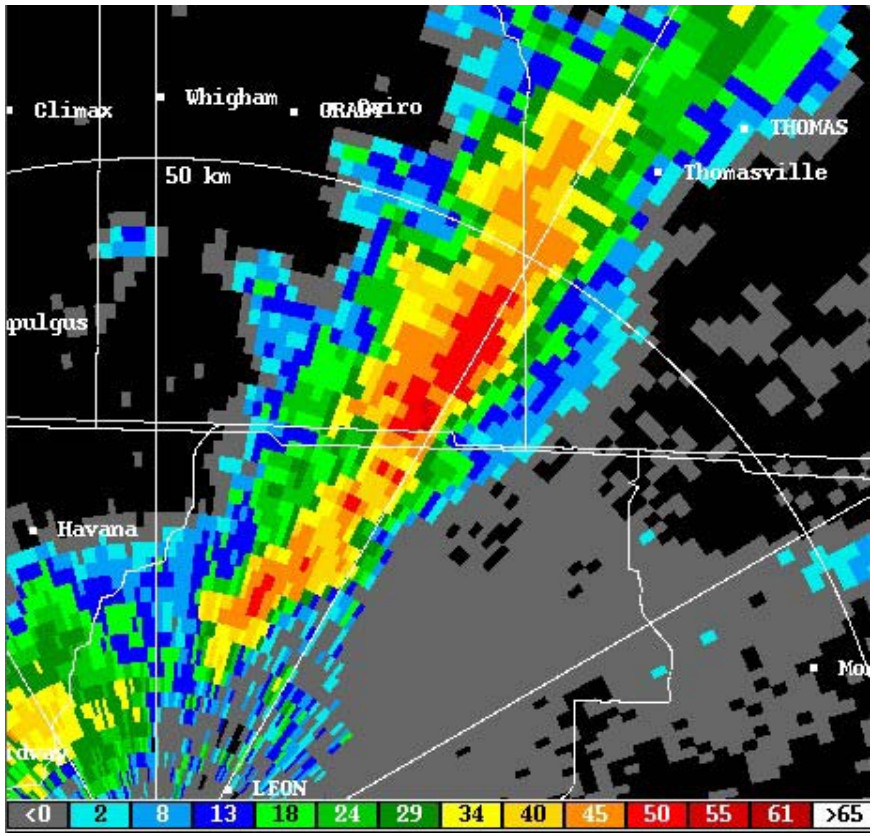
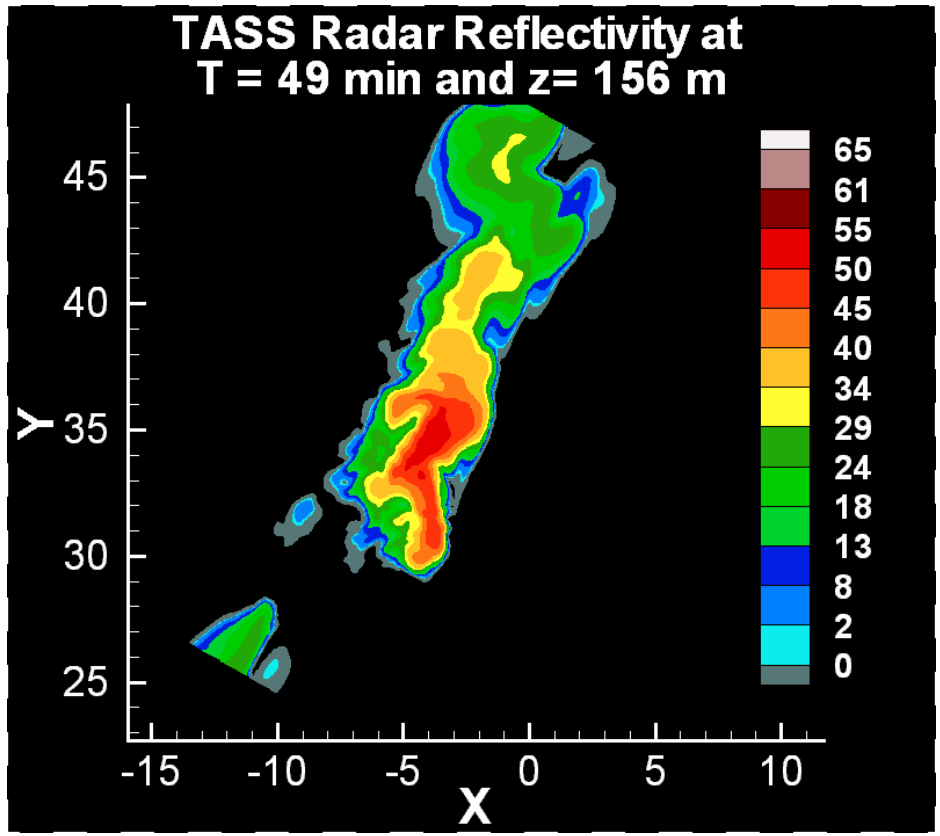
Radar reflectivity near ground (*dBz*)



PPI Display From TLH Nexrad
(1.4° tilt)



TASS
(Horizontal Cross Section)
(major tick every 5 *km*)

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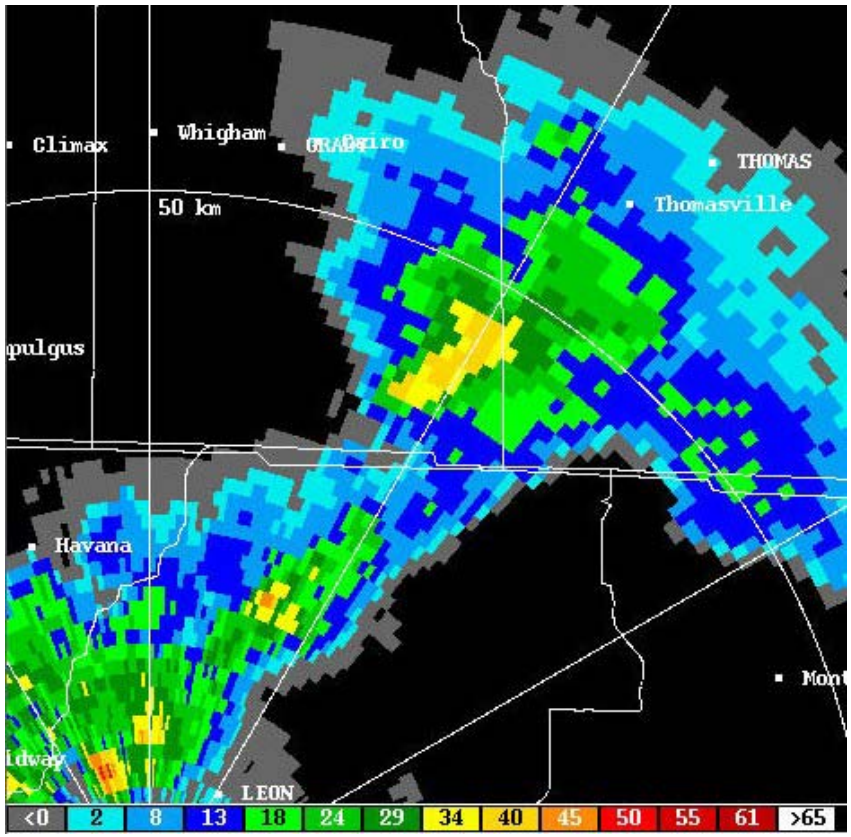
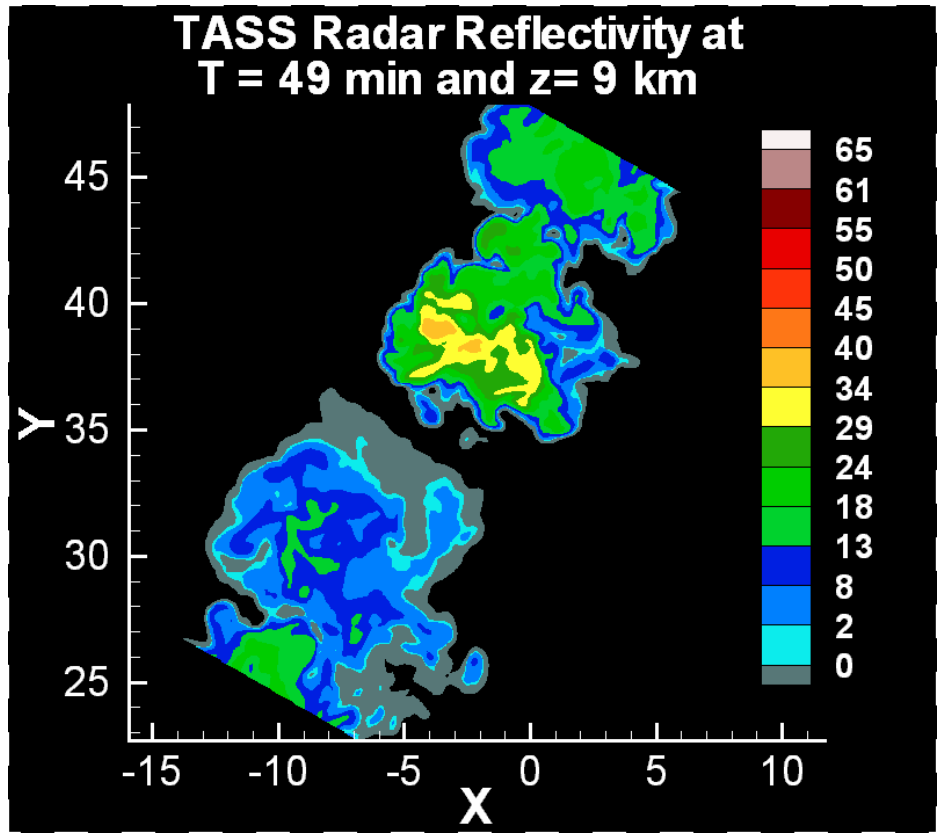
Upper-Altitude Structure of Convective Line



PPI Display From TLH Nexrad
(9.8° tilt)



TASS
(Horizontal Cross Section
at 9 *km* AGL)

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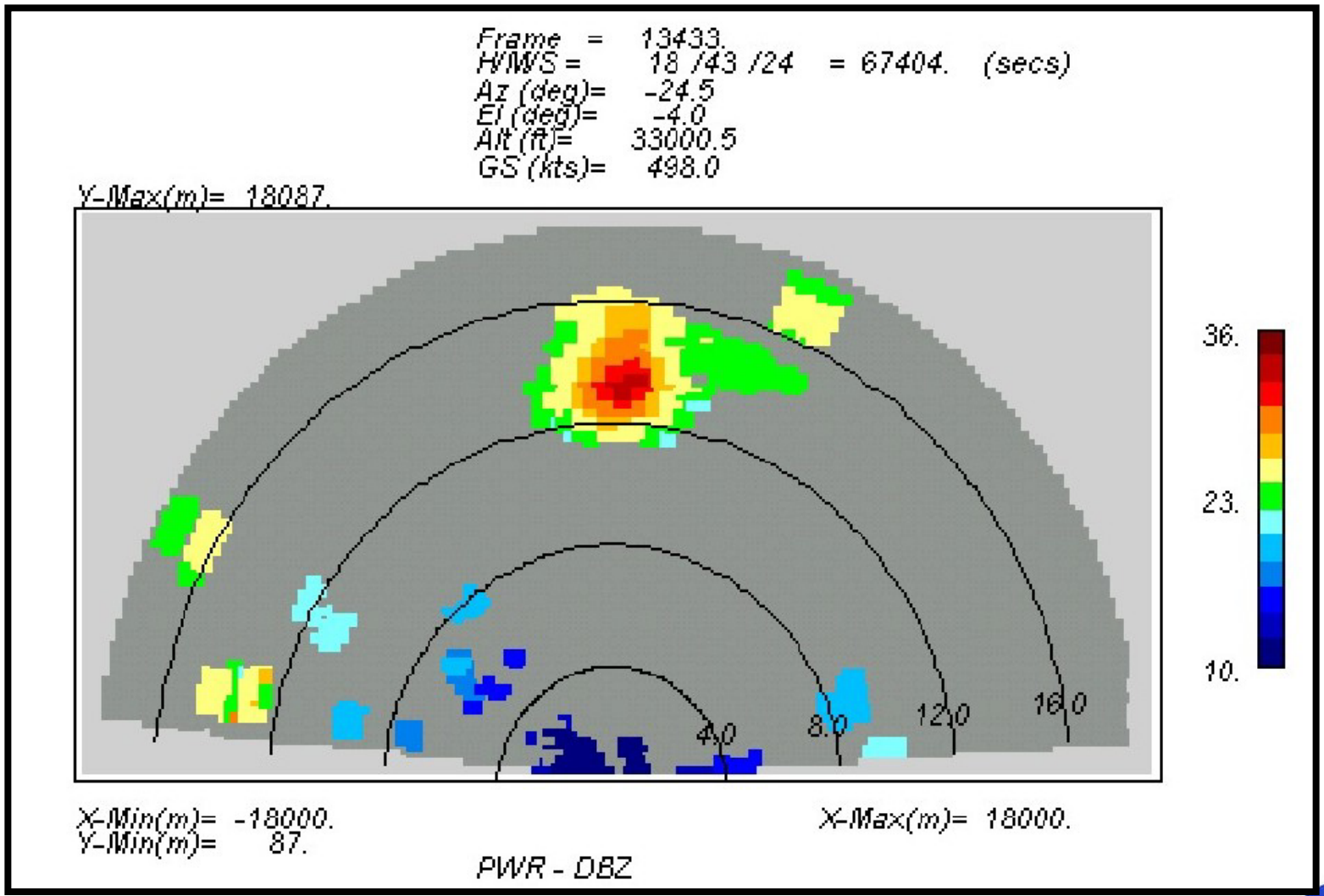
Radar reflectivity from onboard turbulence radar (dBz) at –4º tilt. (Range rings every 4 *km*)



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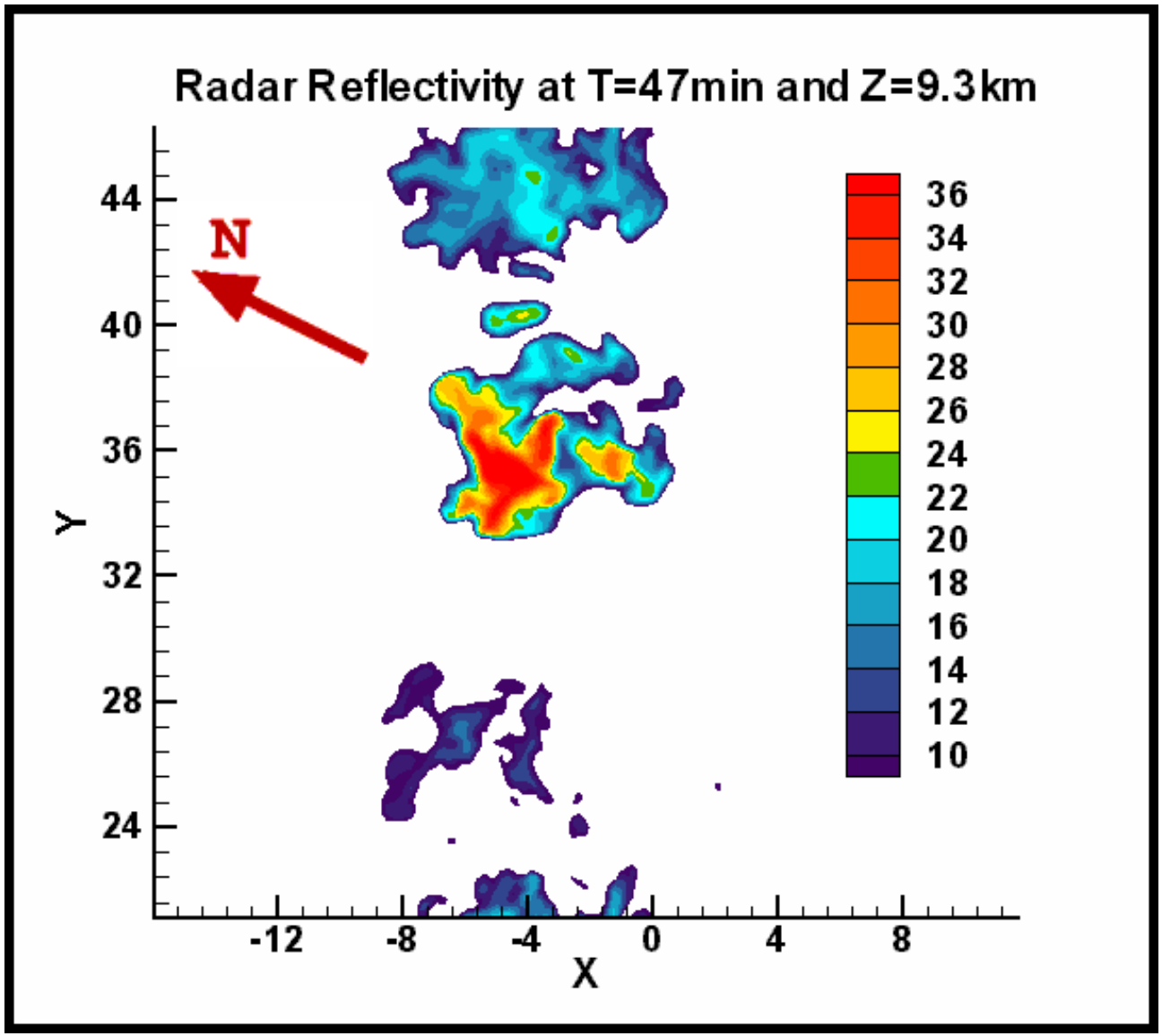
TASS radar reflectivity (dBz) at 9.3 *km* altitude corresponding to time and location of echo in previous slide (major ticks every 4 *km*)



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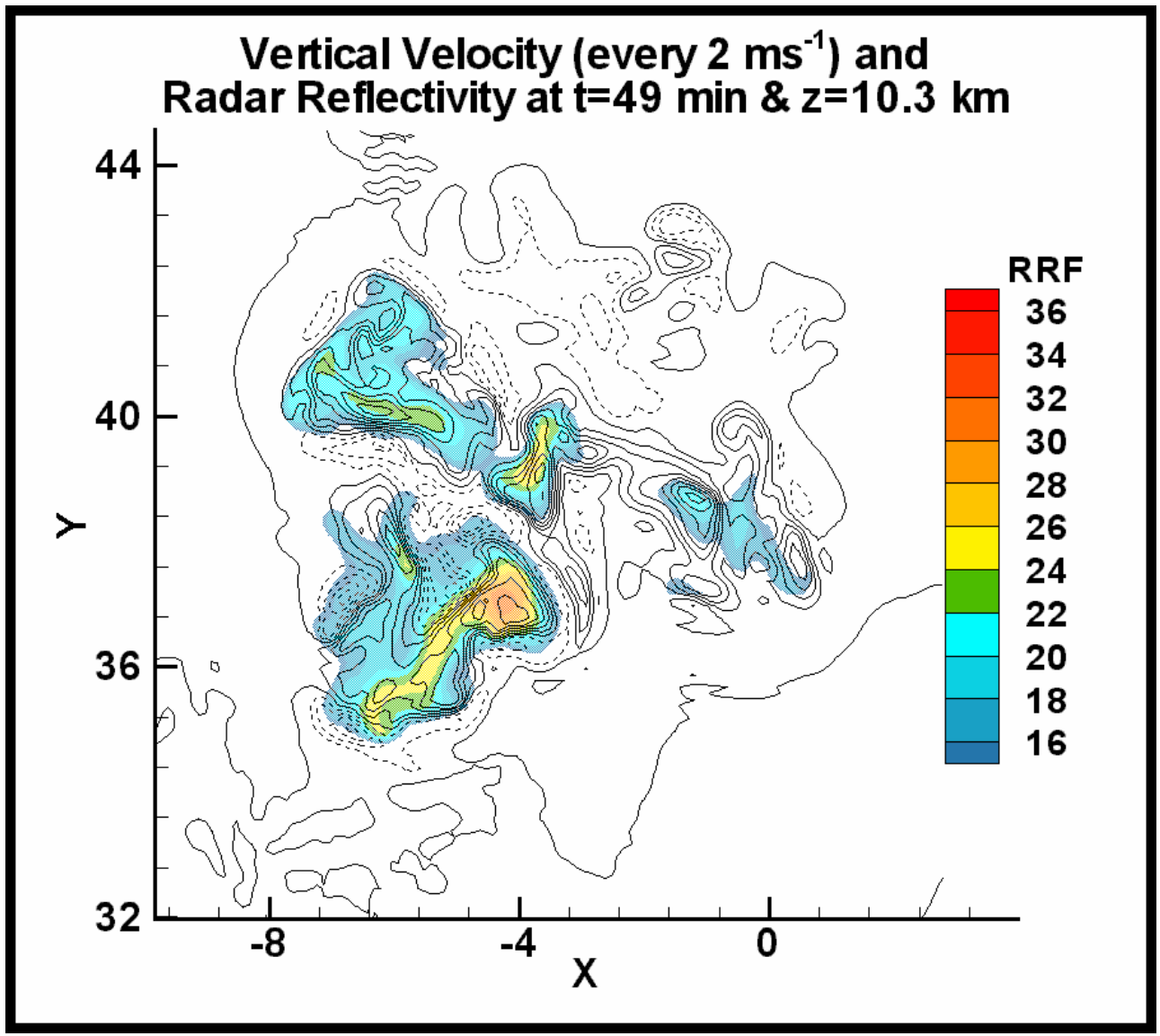
TASS radar reflectivity (dBz) at 10.3 *km* altitude (major ticks every 4 *km*)



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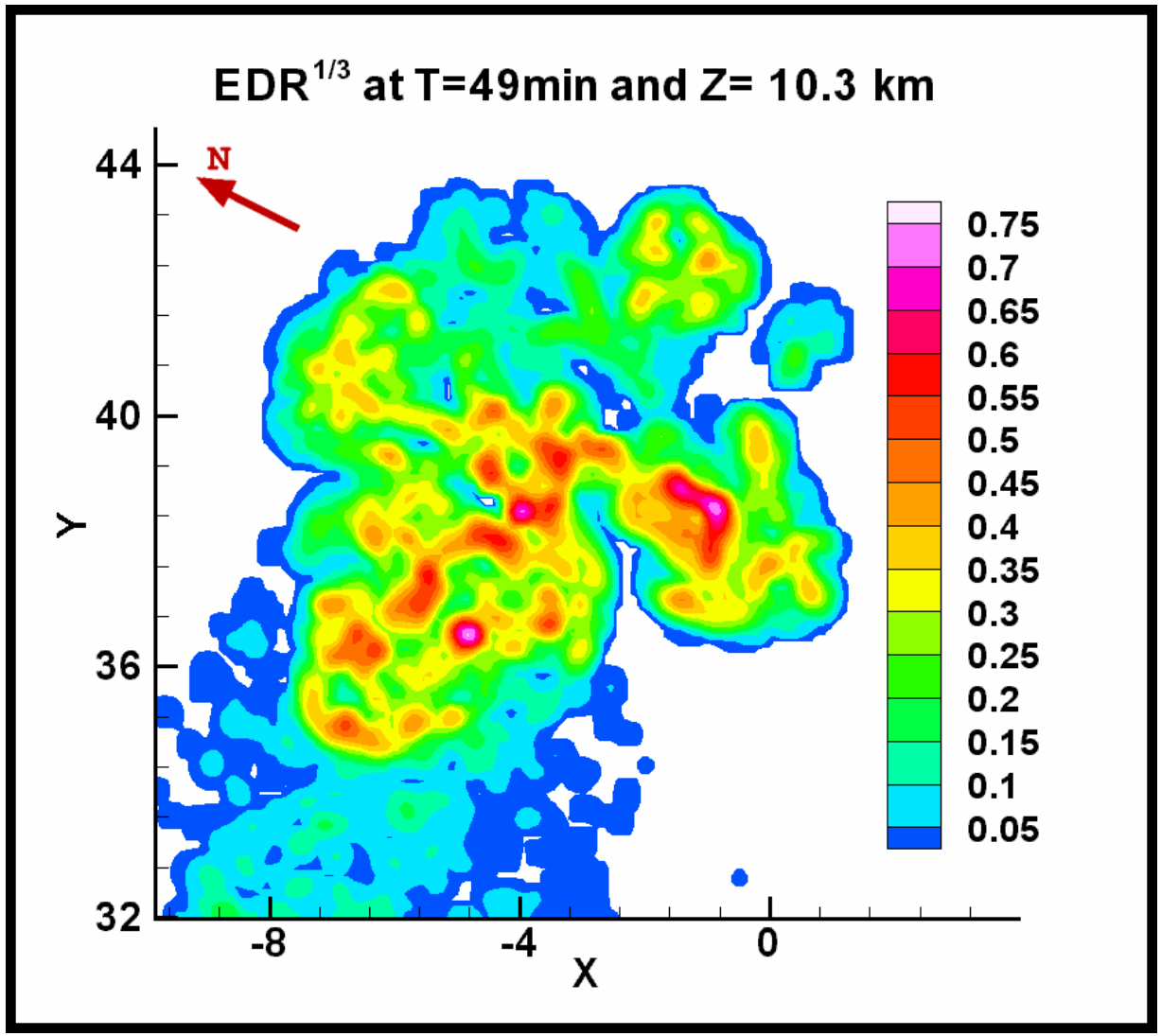
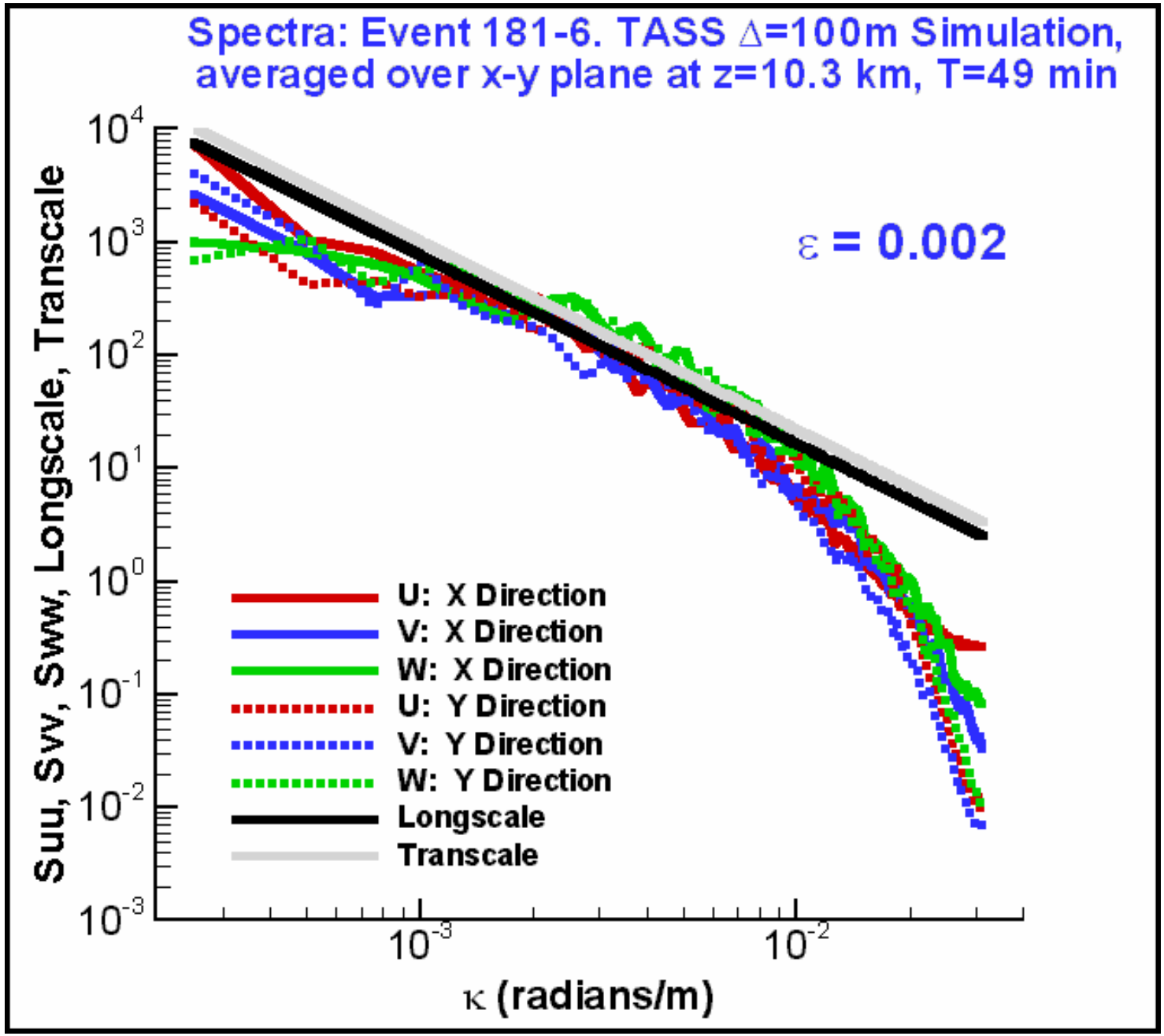
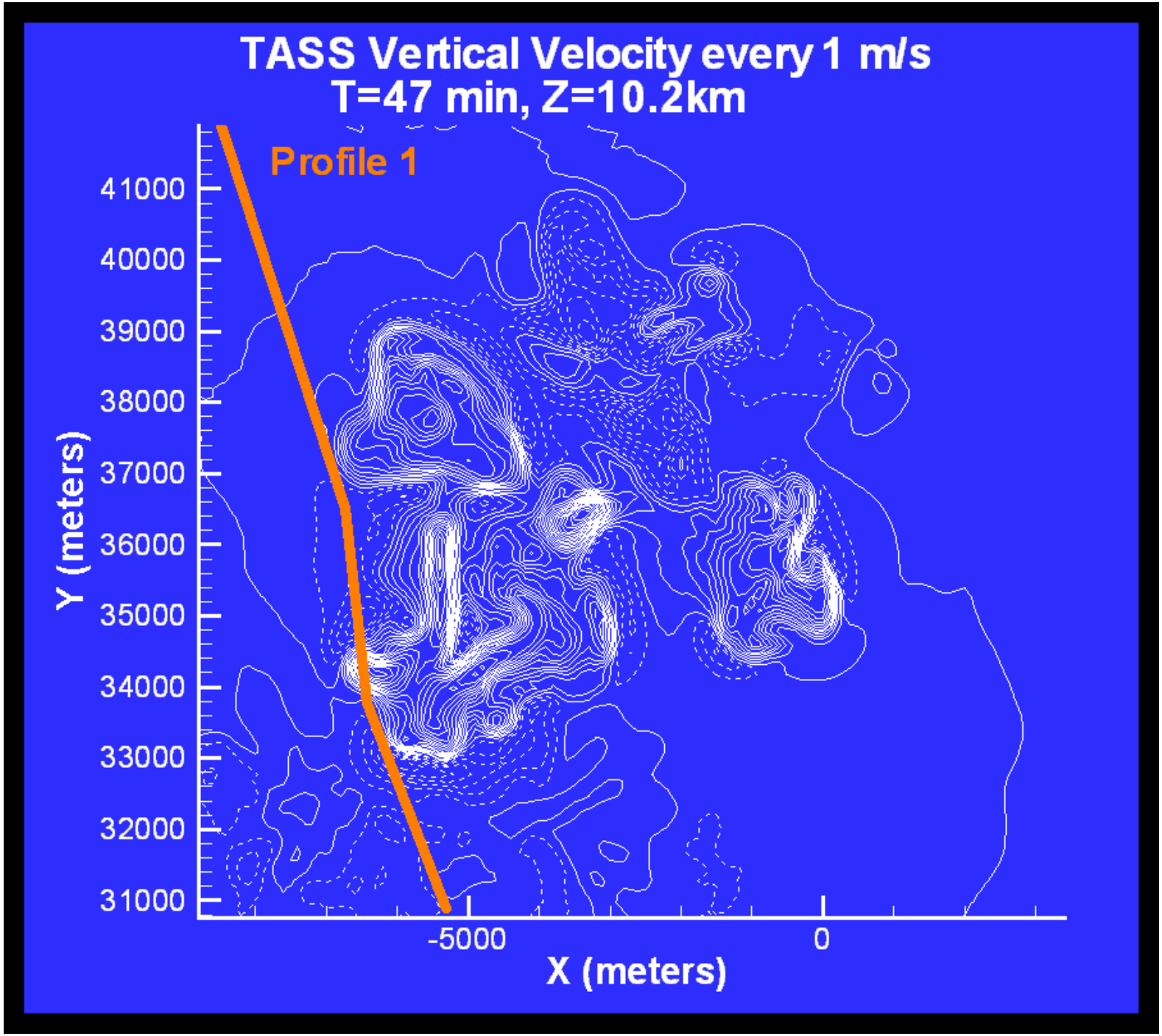
TASS Eddy Dissipation Rate to the 1/3 power ($m^{2/3}/s$) at time and location corresponding to previous slide.



FHP-DWH

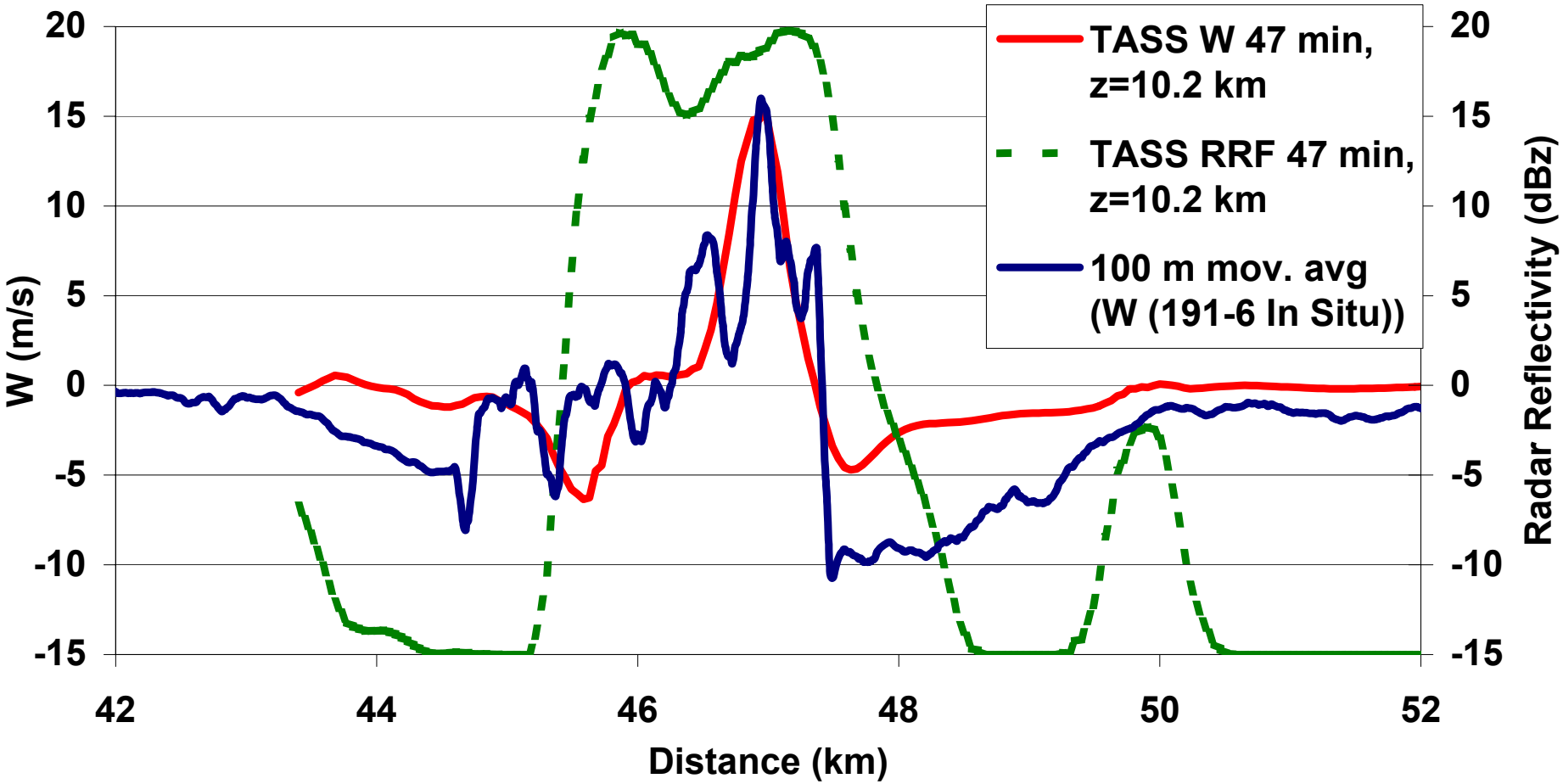

Spectra: Event 181-6. TASS Δ=100m Simulation,
averaged over x-y plane at z=10.3 km, T=49 min
ε = 0.002
Suu, Svv, Sww, Longscale, Transcale
κ (radians/m)
U: X Direction
V: X Direction
W: X Direction
U: Y Direction
V: Y Direction
W: Y Direction
Longscale
Transcale

FHP-DWH

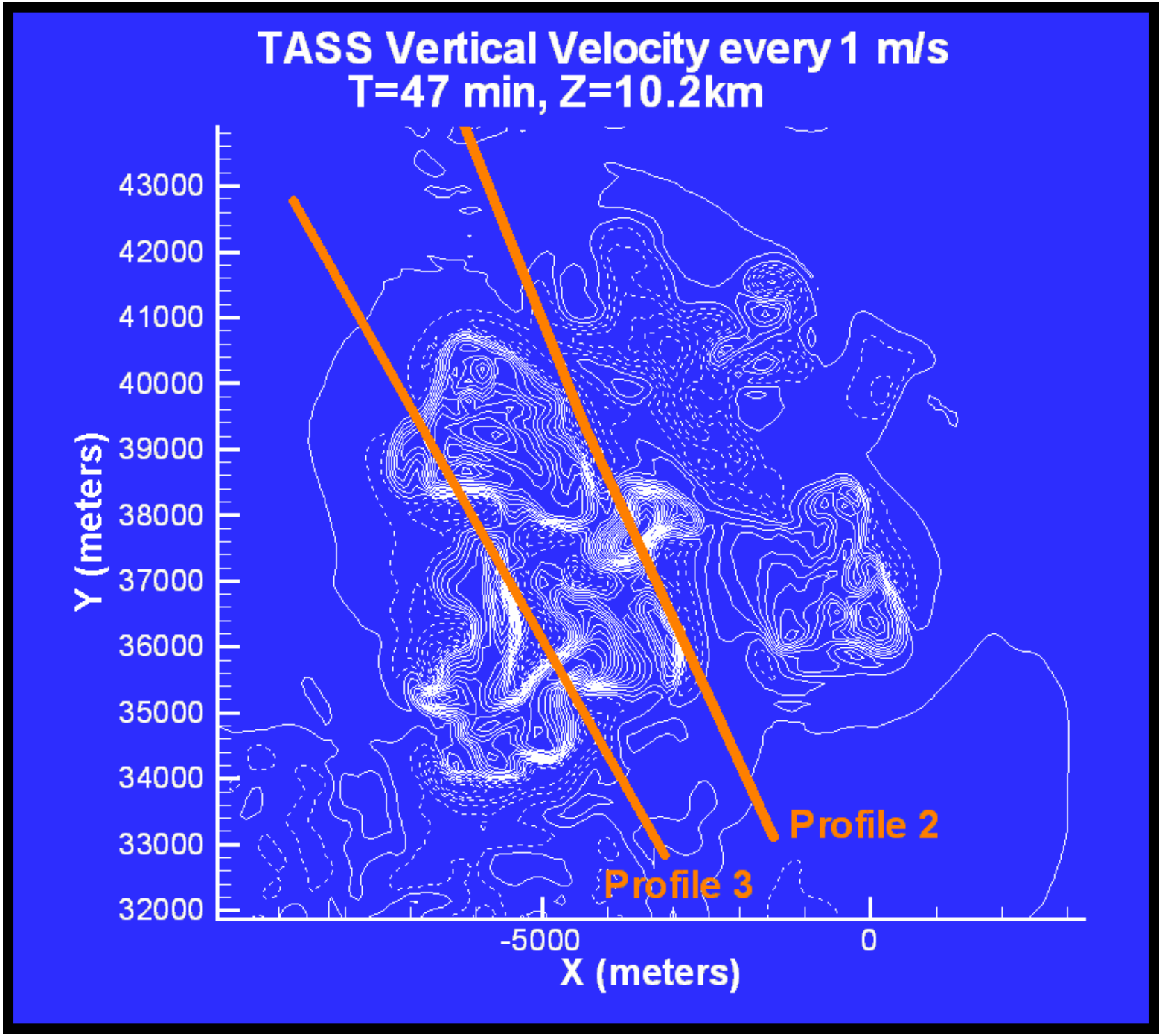

TASS Vertical Velocity every 1 m/s
T=47 min, Z=10.2km
Profile 1
41000
40000
39000
38000
37000
36000
35000
34000
33000
32000
31000
Y (meters)
-5000
0
X (meters)

FHP-DWH

Profile 1: Comparison of 100*m* TASS with *In Situ*

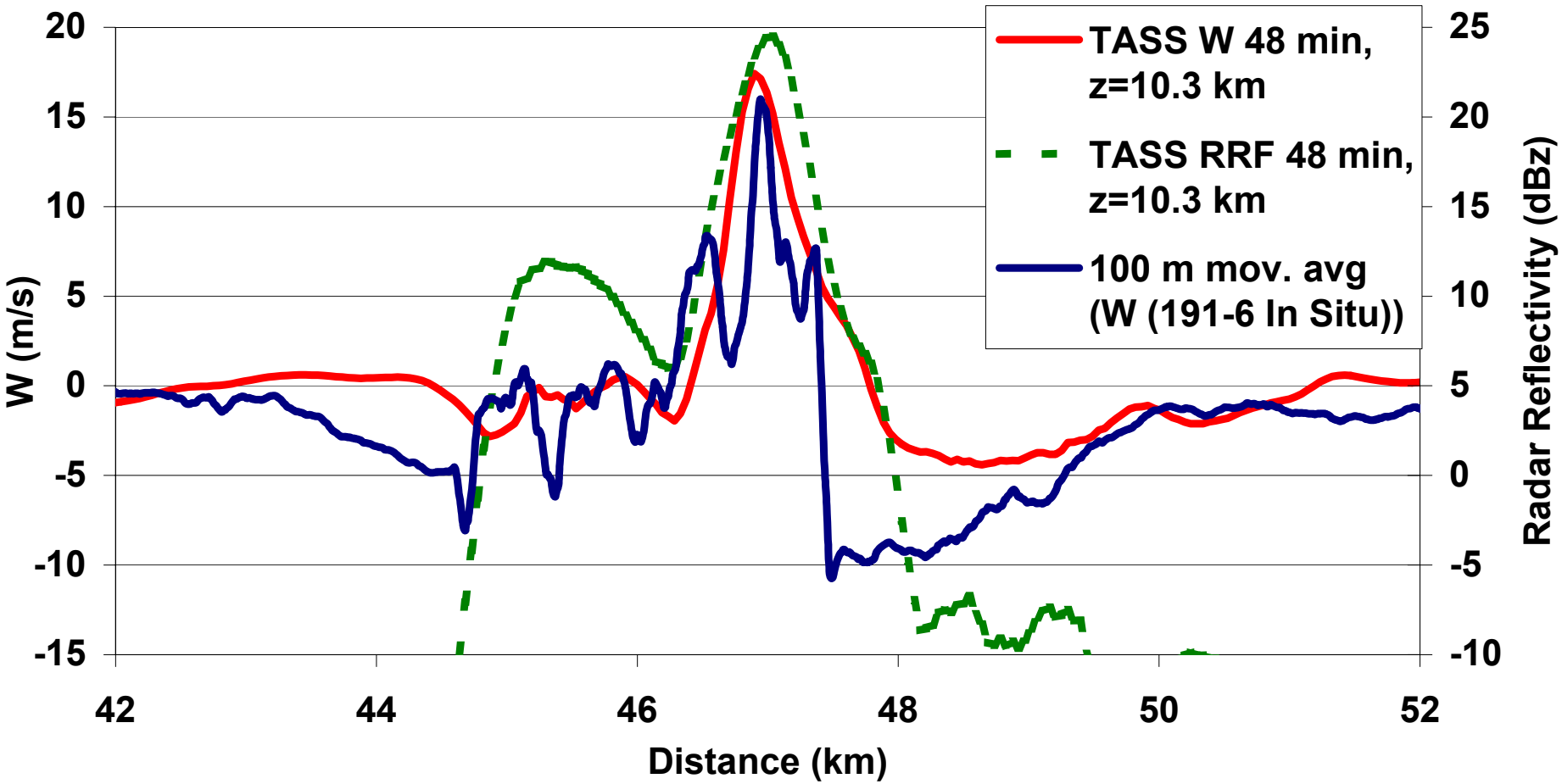


FHP-DWH


TASS Vertical Velocity every 1 m/s
T=47 min, Z=10.2km
43000
42000
41000
40000
39000
38000
37000
36000
35000
34000
33000
32000
Y (meters)
-5000
0
X (meters)
Profile 2
Profile 3

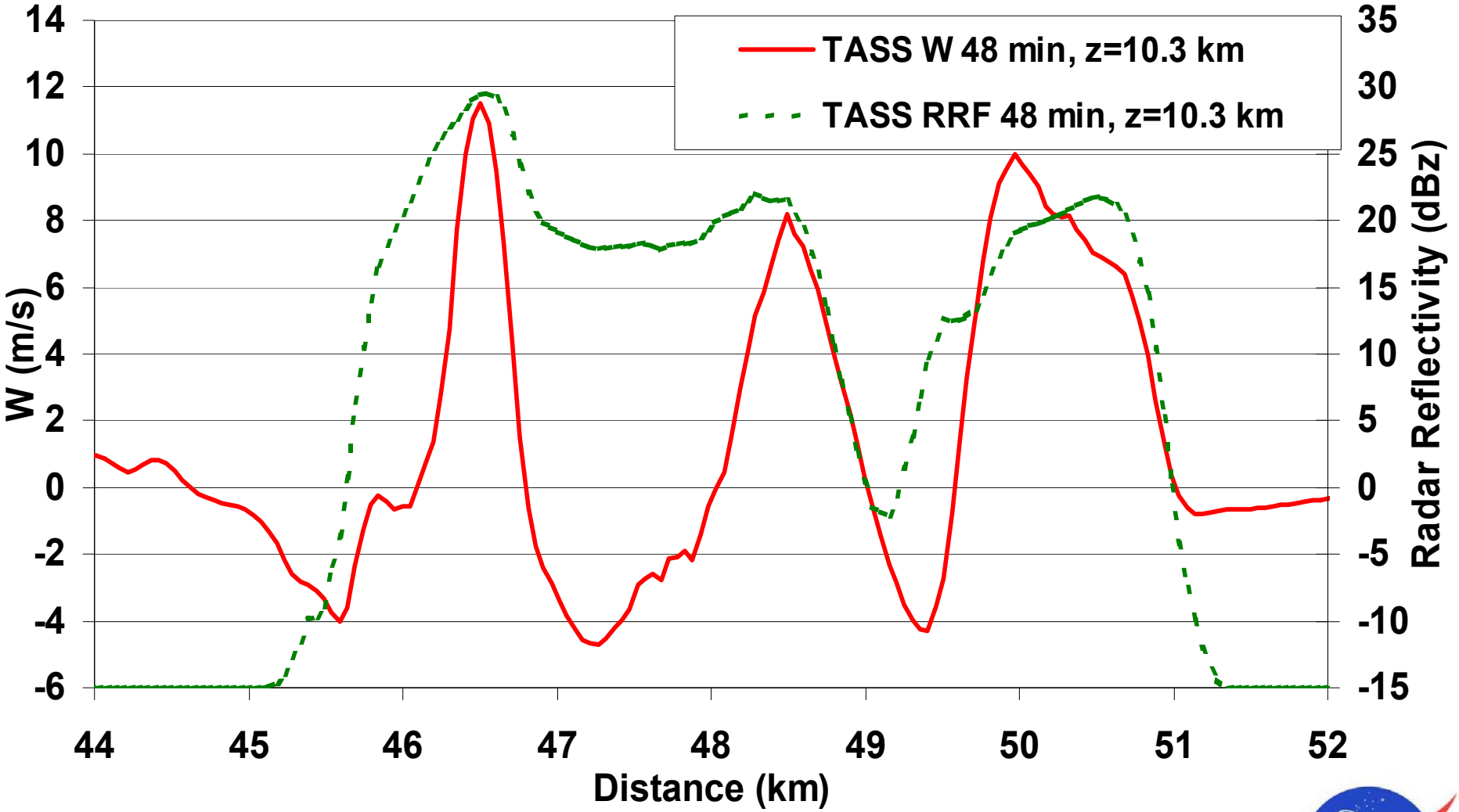
FHP-DWH

Profile 2: Comparison of 100*m* TASS with *In Situ*



FHP-DWH

Profile 3: Comparison of 100*m* TASS with *In Situ*



FHP-DWH

Summary

- Results from 100 m Simulation Show Excellent Comparison with Observed Data
- Turbulence Associated with Buoyant Plumes in the Thunderstorm Upper-Levels
- Regions of Strong Vertical Velocity Found in Regions with Weak Radar Reflectivity
- Details of Storm Structure Differ From Measurements but Larger-Scale Captured by Simulation

Future/Ongoing Work

- Finer Grid Resolution Needed to Capture Important Scales of Motion that Affect Aircraft Normal Load Accelerations
- Data Set from the Case Delivered to NCAR for Addition of Small-Scale Karman Turbulence
- A Nested-Grid with Grid Size of 25 m to be Applied in Future Simulation